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DIAMOND DRILLING OF BLAST HOLES LAKE SUPERIOR
DISTRICT IRON-ORE MINES



BY

ERNEST W. JOHNSON AND FRANK E. CASH

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By Ernest W. Johnson^{2/} and Frank E. Cash^{3/}

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INTRODUCTION

Diamond drilling of some blast holes in stoping operations is practised in at least two iron mines in the Lake Superior district - the Soudan mine of the Oliver Iron Mining Co., on the Vermilion range at Soudan, Minn., and the Anvil-Palms mine, operated by Pickands, Mather & Co., on the Gogebic range at Bessemer, Mich.

Diamond drilling at the Soudan mine has partly replaced percussion drilling because of the extreme hardness of the ore and of the lean formation. According to Wolff,^{4/} the jasper or lean formation in this mine is the hardest rock regularly drilled in any commercial operation.

Diamond drilling of blast holes at the Anvil-Palms mine is used to a limited extent because the ore is hard and because it occurs in a narrow vein underlain by an unstable footwall rock.

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- ^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7317."
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- ^{4/} Wolff, W. P., Drilling in Stopes at the Soudan Iron Mine: Paper delivered at the regional meeting, Am. Inst. Min. and Met. Eng., Duluth, August 12, 1941, and published in Skillings' Mining Review in the September 13, 1941, issue.

No change in mining method is involved at the Soudan mine when percussion drills are replaced by diamond drills. However, at the Anvil-Palms mine a stoping system of mining is substituted for the usual sublevel-cave system to take advantage of the deep holes made possible with diamond drills.

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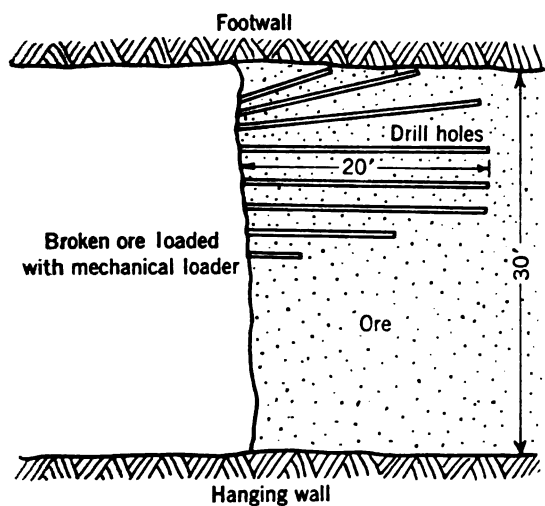
Clyde M. Pearce, formerly mining engineer, Health and Safety Branch, Bureau of Mines.

Soudan Mine

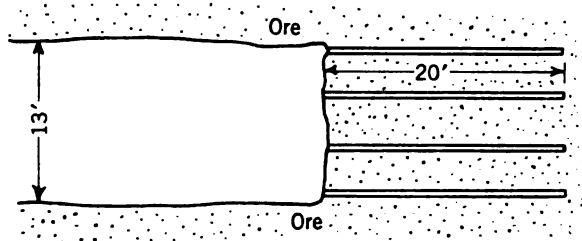
Iron ore was discovered in 1865 on the property now being operated as the Soudan mine. The ore body was prospected and explored in 1875, and the first shipment of ore from the Soudan mine, in 1884, also had the distinction of being the first shipment of iron ore from Minnesota. A total of 12,627,326 tons was shipped from 1884 to 1943, inclusive, and iron-ore shipments from this mine in 1943 amounted to 215,000 long tons.

The mine has a number of ore bodies, dipping steeply at 70° to 80° and occurring in three different horizons. The ore bodies vary to 70 feet in thickness and to 500 feet in length. For best stoping conditions, an ideal ore body is 30 to 40 feet in width and 200 feet or more in length. The ore is very hard, dense hematite. In mass, it has a few parting surfaces, which tend to be horizontal, that aid in breaking but are avoided in drilling. The wall rocks are usually sericite schist or chlorite schist commonly called greenstone, and are not competent as compared to the iron formation. In many instances jasper occurs along the walls between the ore and the greenstone and frequently as "horses" in the ore. The boundary between ore and jasper often is not well-defined.

Operating levels are 100 or 200 feet apart vertically. Development drifts are planned to be in greenstone, inasmuch as drifting in jasper is carefully avoided. The greenstone, or "rock" as it is called in the mine, is in no way extraordinary. It compares well with other hard rocks; it can be drilled faster but breaks less readily than average granite. Although this report is principally concerned with ore drilling in stopes, rock and jasper are mentioned, and some drilling data are given to present comparisons.

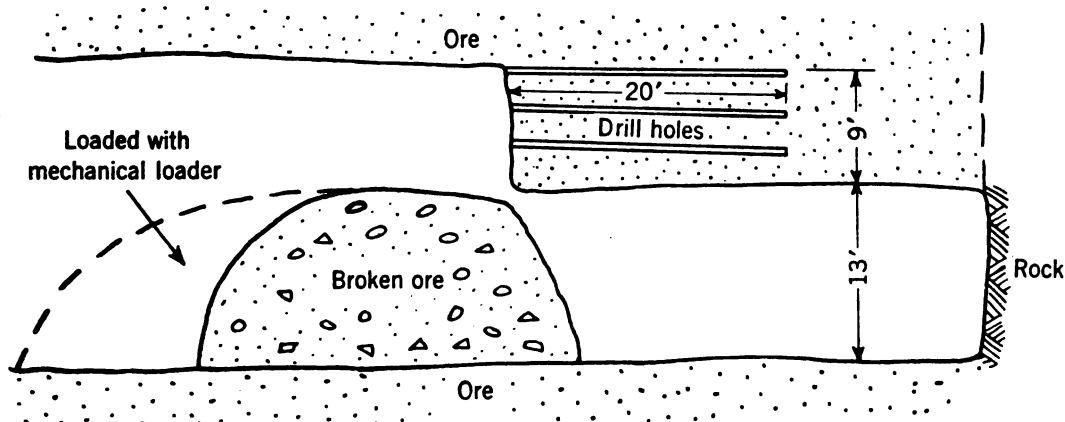


Plan, breast stope



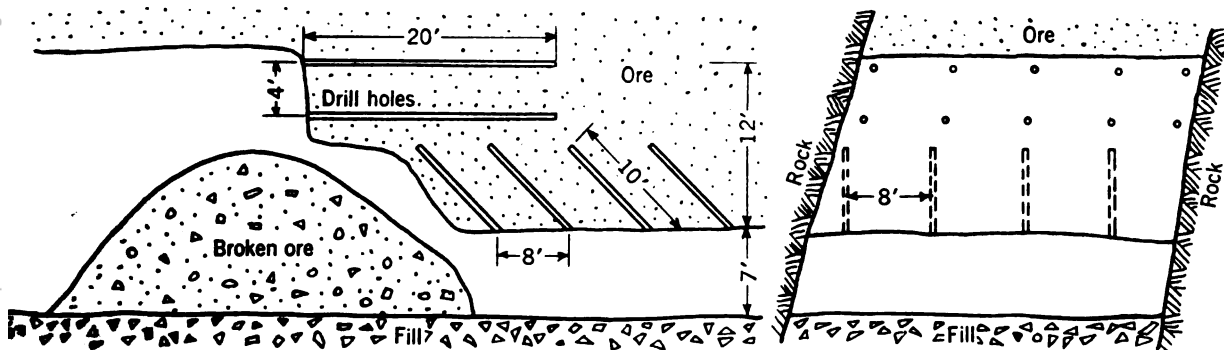
Longitudinal section, bottom breast cut

A



Longitudinal section, top breast cut

B



Longitudinal section

Cross section

Diamond drilling in a back stope

C

Figure 1.—Diamond drilling of blast holes, Soudan mine, Oliver Iron Mining Co., Soudan, Minn.

The mining method in use is back stoping and filling. When a drift opening reaches an ore body, the first ore is taken out by "breast stoping" to the full width and length of the ore body to a height of about 22 feet. The breast is advanced in two benches, the bottom cut being about 13 feet in height and the top cut 9 feet (see fig. 1, A and B). In breast stoping operations all of the broken ore is loaded into cars with mechanical loaders. Following the breast-stoping operation, a drift is built by erecting timber sets and covering them with lagging. Cribbed chutes are then built along the footwall side of the drift, and cribbed raise openings for manways are built along the hanging wall. Next, a raise is driven in the wall rock to the level above; there may be two or three such raises if the stope is long enough; waste rock is dumped into the stope or drawn from the worked-out stope above. This waste is spread with scrapers and tugger hoists until the stope opening outside the drift and cribbed openings is filled to within 7 feet of the back.

With the first "fill" completed, back stoping begins, and the ore is mined in successive cuts, each about 12 feet high. Following the opening cut in the back, drilling is done from the top of the ore pile (see fig. 1, C). The broken ore is drawn into the chutes with scrapers operated by three-drum tugger hoists. In spite of its hardness and the difficulty in drilling, the ore breaks well, the tonnage broken for each foot of hole being fairly large. At times, mudcapping is used to break some of the larger chunks resulting from the primary blasting. As each stoping cut advances the raise openings are cribbed up, and the stope is again filled to within 7 feet of the back.

Available diamond-drilling equipment is limited, so about 40 percent of the stope drilling is still done with percussion drills. Both stopers and drifters are wet-type machines. Drifters with 3-1/2-inch pistons have not proved successful when drilling in ore; their use gives some increase in drilling speed, but this advantage is lost in delays caused by excessive breakage of drill bits and rods. They drill rather well in rock, but even in softer material a considerable amount of steel breaks.

All percussion drilling is done with heavy, detachable cross bits, which are 2 inches in diameter and 2-1/2-inches in length when new, are double-tapered, have a center hole and have a cutting edge of 105°. The bits are reground and retempered in the mine shop on the surface; each bit is treated an average of 5-1/2 times and is discarded when worn to a diameter of 1-23/32 inches, as clearance is too small for effective drilling.

Drill rods are made from 1-1/8-inch round hollow steel 3 to 8 feet in length. They are made in the mine shop, with Leyner lugs on the shanks and ends threaded for bits.

Table 1, giving percussion-drill-operation performance for April 1941, is of interest as it indicates that the effective life of the bits in greenstone is 10 times as long as in ore and jasper, and the rate of drilling is five times as great in the greenstone.

TABLE 1. - Percussion-drill operation

	Material drilled			
	Ore	Jasper	Greenstone	
Bits used.....	36,551	2,485	1,765	40
Feet drilled.....	10,016	657	4,765	
Drilling time ¹ /..... minutes	219,000	15,960	21,120	
Distance drilled, each bit,... inches	3.29	3.17	32.40	
Distance drilled a minute ¹ /..... do.	.55	.49	2.70	
Bits used a day.....	1,741	118	84	1

¹/ Drilling time is the total elapsed time after the machine is set up ready to drill, until drilling is finished.

A change from hand-fed percussion drills to drills fed by automatic mechanical means was made largely to improve the working conditions of operators. The intense vibration conveyed to the driller in adjusting the screw feed was eliminated by the automatic mechanical feed. The use of electrically operated diamond drills improves working conditions further since they are practically noiseless in operation.

Before detachable bits were used, a big problem was the transportation of integrally forged-bit drills. In one instance, 138 drills were used drilling a single hole 87-1/2 inches in depth. The 1-1/4-inch hollow-st drills weigh 3.9 pounds a foot; and assuming the average drill length is 10 feet, the weight of steel used would total 2,690 pounds.

Considerable economy results from the use of detachable bits, as the aggregate weight of 138 bits would be about 100 pounds, and only one or two sets of drill rods (from 3 to about 8 feet in length) are required for each machine. When all drilling was done with percussion drills, as many as 3,500 detachable bits were used in a day. The bits and replacement rods weighed about 3,000 pounds. If the same number of forged-bit drills had been used, the aggregate weight would have been about 68,250 pounds.

Furnishing bits for diamond drills at the working faces presents no problem. An average of 4 feet is drilled with a bit before it has to be redressed, and a drill runner can carry a box containing 24 bits under his arm.

Two other methods of making blast holes were tried in the Soudan mine and, although unique in nature and found impractical, are believed worthy of a brief description. One method was to burn a hole with an oxyacetylene torch, using a 10-foot length of pipe for a burning tip. Mine officials who witnessed the experiment stated that holes started easily and that progress was fairly rapid but that the pipe was also consumed. Later, a water-jacketed burning tip was developed and tried, with the result that holes of 8- and 10-foot depths were burned at rate of speed similar to that attained with the use of a diamond drill.

The second method tried was to burn a hole with an electric arc. In doing this, one electrode was grounded and the other was used for burning the hole. Holes to 4 feet in depth were burned.

The advantages of diamond drilling over percussion drilling of blast holes in the Soudan mine stopes are now well-established. The early use of diamonds for stope drilling was closely related to exploratory drilling and was made possible only because abrasive carbons were cheap at the time. The present-day use of diamonds for production drilling and its very rapid development in a number of Canadian gold and copper mines, Australian gold mines, on the Rand in South Africa, and at the Soudan mine are possible because new techniques have made it practical to employ relatively low-priced portz in diamond bits. The development of these new techniques was more closely related to the tool-making trade than to any phase of mining.

The first experiments at the Soudan mine with production diamond drilling were begun in June 1938. An electrically operated exploration drilling machine, equipped with standard drill rods and core barrel, was used. The machine had a hydraulic feed and was driven by a 10-horsepower motor. For test purposes it was equipped with special water piping and gages and with a recording wattmeter.

These experiments lasted over a 10-month period and yielded a great deal of carefully recorded data on speed, water pressure, bit pressure, horsepower, and the design of bits. Early in the program, bits of the "insert" type were tried but were replaced by solid-face ring-type bits. These were tested with two, four, and six waterways of various widths. Tests were run using "cast-set" bits, but their useful life was found to be too short in drilling hard ore, and they were discontinued in favor of bits with "impregnated" crowns. Other tests were run in ore, jasper, and rock with bits of varied densities and sizes of diamonds. Similar tests were made with bits having matrices of different hardness.

Technical Publication 1172 of the American Institute of Mining and Metallurgical Engineers^{2/} gives a report on these tests, with some of the principal results.

The specifications for bits that resulted from the tests govern the bits that are being used today; they are:

Ring-type bit with a diamond-impregnated crown having six radial waterways, each 1/16-inch in width.

Size, EX special, o.d. 1.468 inches, i.d. 1.000 inch.

Diamonds, 14- to 20-mesh in a medium-hard matrix for drilling ore.

28- to 35-mesh in a medium-soft matrix for drilling jasper.

10- to 14-mesh in a very hard matrix for drilling ore.

These bits have a crown 1/4-inch high, of which about 85 percent is consumed in useful drilling. For size comparison, the standard EX bit used in exploration has an outside diameter of 1.468 inches and an inside diameter of 0.860 inch.

^{2/} Weslow, W. C. Use of Diamond-Impregnated Cemented Carbide for Core Bits: Am. Inst. Min. and Met. Eng. Tech. Pub. 1172, March 1940, 12 pp.

The best drilling results were obtained with a hydraulic pressure on the bit of 1,500 to 1,600 pounds per square inch. Most of the drills are being operated at a constant speed of 1,200 r.p.m. under varying pressure but drills are in use on which the bit speed and pressure are manually adjusted according to the hardness of the material being drilled. These latter machines, like the others, are electrohydraulically operated and thought to be ideally suited for the work. The drilling machines weigh about 235 pounds.

A brief test was run in January 1940 on a diamond drill operated with compressed air. It was a column-mounted machine with a standard screw-feed head and a 10-horsepower vane-type motor. It drilled satisfactorily, but the air consumption was judged to be excessive.

The following experience indicates further the extreme hardness of some ore in the Soudan mine. While drilling with percussion drills and forged-bit drills, a crew on one shift drilled 16 inches and used 165 drills and on the following shift another crew drilled 18 inches while using 176 drills. An average of one-tenth inch was drilled with each drill, and each drill was in actual use an average of 2 minutes. The average drilling rate was 2.8 inches an hour.

A maximum of 12 to 15 feet of hole a shift is drilled with a percussion drill. About 40 feet maximum and an average of 28 feet are drilled with a diamond drill, with actual drilling in progress for 6 of the 8 hours comprising a shift. Generally, drilling 40 feet of hole requires about 20 changes of bits.

Interesting comparative drilling-performance data from April to October 1940 were obtained in a stope where the ore was uniformly harder than in other sections of the mine. These data are given in table 2. The 3.75-horsepower machines drilled 3,000 feet of holes during that time. The performance of the 5-horsepower drill is for 1 month, for which data were available, and for comparison, the performance of percussion drills in the same stopes during all of 1940 is given.

The advantage of the diamond drill over the percussion drill is apparent from the figures given, and the increased advantage of a machine with correct power and speed is also indicated. The table, of course, shows only the advantage gained in drilling speed. Added to that is the fact that the diamond drill can drill about three times as much hole from a single set-up as a percussion drill, with a corresponding saving in time for setting up and tearing down machines.

The performance of diamond drills at the Soudan mine since 1940 is summarized in table 3.

In the matter of breaking ground, the long holes of the diamond drill and the short holes of the percussion drill are about equal. Each breaks about 2 tons of ore for each foot of hole.

TABLE 2. - Comparative drill performance, inches

	3.75-hp. Diamond drills	5-hp. Diamond drills	Percussion drills
Distance drilled a minute, elapsed time/.....	0.814	1.061	0.400
Distance drilled a minute, actual drilling time	1.243	1.760	1.200
Distance drilled with each bit used.....	14.21	21.59	-

Elapsed time as used is the total time after the machine is ready to drill, until it is ready to be taken down. It includes all ordinary delays but not the time required to rig up or tear down.

TABLE 3. - Diamond-drill performance

Year	Feet drilled	Inch per minute	Inches per bit
1941.....	17,588.33	0.9649	24.76
1942.....	55,215.25	.8434	26.16
1943.....	56,404.50	.8825	42.17
1944 to June.	29,172.68	.9520	48.83

Since the advent of diamond drilling at the Soudan mine, there has been an estimated reduction of 35 percent in the cost of blast-hole drilling, in addition to a 20-percent reduction obtained by substituting detachable bits for forged-bit drills.

Holes drilled with bortz bits are about 1-1/2 inches in diameter; they are uniform in size from start to finish and range in depths from 10 to 20 feet to suit the stoping operating cycle. They are loaded with 45-percent gelatin dynamite, in 8- by 1-1/8-inch cartridges, to within about 24 inches of the collar. Seven-foot lengths of fuse are capped with No. 6 detonators for making primers; about 15 inches of fuse projects from the hole after loading. Loaded holes are fired in groups, but the order of igniting the fuses results in charges detonating singly.

The diamond drill definitely has established a place for itself in hard-ore stoping conditions at the Soudan mine. It has been found adaptable to all stoping conditions in the mine; use of the diamond drill in drifting operations is in the experimental stage.

An excellent start had been made in proving the worth of diamond drills for mine-production drilling. Satisfactory bits are available, and the design and construction of new machines, backed by sound engineering, are being carried on by responsible manufacturers. Hard-rock mine operators constantly demand faster, cheaper drilling. The near future doubtless will produce further interesting and profitable developments.

ANVIL-PALMS MINE

The first shipment of ore from the Anvil-Palms mine was made in 1887. Over 15,000,000 long tons of high-grade hematite iron ore has been produced; the current annual production rate is about 600,000 tons.

The ore occurs in two separate veins which dip about 72° N., each vein averaging about 10 feet in thickness. The foot wall is quartzite, grading downward into slate and resting on a granite and greenstone base. The hanging wall is lean iron formation.

As stated in the introduction, diamond drilling of blast holes in the Anvil-Palms mine is being conducted on an experimental basis, because of the hardness of the ore and its occurrence in two narrow veins underlain by an unstable footwall rock. These conditions do not make mining by either of the usual sublevel-caving or sublevel-stopping methods wholly desirable.

The decision to experiment with diamond drilling of blast holes, in conjunction with an open-stope system devised to give full advantage to this type of drilling, followed an inspection trip in the fall of 1941 by two Anvil-Palms mine officials in the Aldermac mine of the Aldermac Copper Corporation, Ltd., at Arntfield, Quebec, Canada; the Moranda mine of Noranda Mines, Ltd., Quebec, Canada; and the Chesterville mine of the Chesterville Larder Lake Gold Mining Co., Ontario, Canada, where diamond drilling of blast holes was in common use.

Except for small-scale experimentation in the new open-stope system in the Anvil-Palms mine is mined by the well-known sublevel-caving and sublevel-stopping systems. The new stopping system in use permits diamond drilling of deep blast holes, which is the chief advantage of this type of drilling as compared to percussion drilling. In percussion drilling the gauge of the bit decreases from wear, and when the bit is changed one of smaller diameter is required. Due to the resultant narrowing diameter of the hole, a practical maximum working depth of hole is about 18 feet. In diamond drilling the hole size remains constant, and desired practical depth of hole is attainable.

Preliminary development for open stopping includes driving a main drift in the ore vein and manway raises at 150-foot intervals. The raises are continued until old caved areas or rock capping are encountered. At a height of 20 feet the raises are connected with a "scraping" drift, and at a height of 36 feet a "blasting subdrift" is driven, also connecting the raises. "Drilling" drifts are then driven between the raises at 60- to 100-foot intervals above the blasting subdrift, until the caved workings or rock capping above is encountered. Generally, two drilling drifts above the blasting subdrift afford the most practical mining arrangement, but almost any variation can be planned, given favorable local conditions and a sufficient depth of ore. The number of blocks that may be developed is limited only by the continuity of the ore or by the desired planning procedure. A "breaking raise" is driven at the end of a block, generally at a break in the continuity of the ore vein. After this raise reaches a desired height it is "slashed" between the foot wall and the hanging wall. In the meantime, mill raises, on 10-foot centers, have been driven from the opening drift to the blasting subdrift; the plan and elevation sketches of this open-stope development procedure and the location of blast holes are illustrated in figure 2. Percussion drills are used in development work.

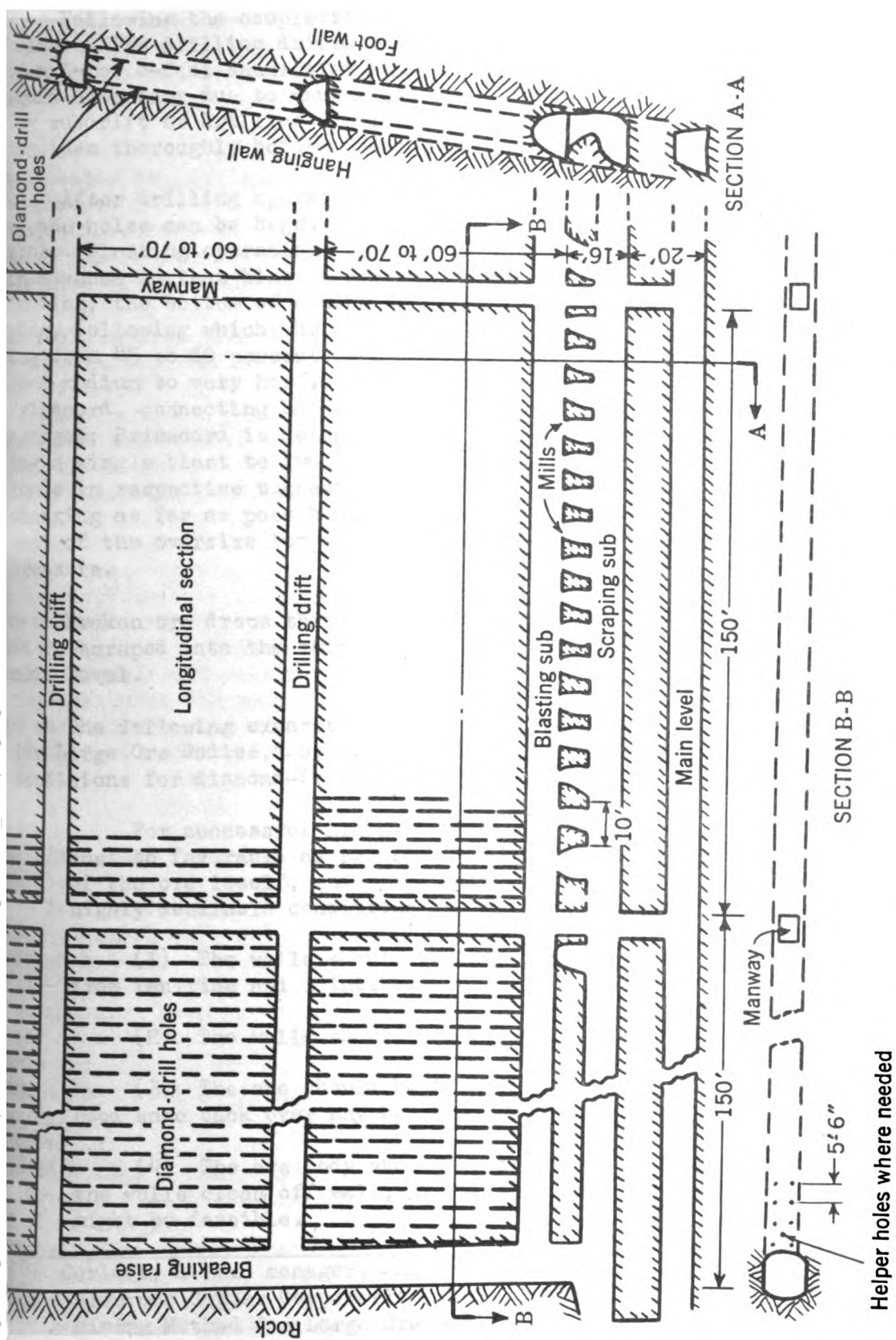


Figure 2.—Diamond drilling of blast holes, Anvil-Palms mine, Pickands Mather and Company, Bessemer, Michigan.

Following the completion of development, diamond drilling of the blast holes in the drilling drifts is begun, holes being put down at each corner of a 5- or 6-foot square; at times a center or "helper" hole is drilled if found necessary due to unusually hard ground. Holes penetrate to the blasting subdrift or drilling drift below, as the case may be, to permit cleaning them thoroughly before the explosives-loading operation is started.

After drilling operations are sufficiently advanced, so that blasting of the holes can be begun, two rows of holes, crosswise of the vein, are shot. Blasting operations in the lower drilling drifts are kept somewhat in advance so that blasted ore will fall into the mill holes below. In loading, the bottom of a hole is first secured with a tightly driven wooden plug, following which the hole is loaded with dynamite, in strengths ranging from 45 to 80 percent, depending on the hardness of the ground, which is from medium to very hard. The top 2 to 3 feet of hole is stemmed with clay. Primacord, connecting holes included in each blast, is used to detonate charges; Primacord is detonated with a blasting cap and safety fuse. Limiting a single blast to two rows of holes permits adjusting the strength of loads in respective succeeding blasts to eliminate overcharging or undercharging as far as possible. Secondary blasting is necessary at times, but most of the oversize lumps of ore are broken with air-operated (pavement) breakers.

Broken ore drops through the mills to the scraping drift below, where it is scraped into the raises and loaded into mine cars from chutes on the main level.

The following excerpt taken from the pamphlet entitled "A Mining Method for Large Ore Bodies," by A. V. Corlett and G. D. McLeod,⁶ lists limiting conditions for diamond-drill holes for blasting:

For successful mining by diamond-drill blast holes, conditions must be favorable as regards strength of wall, 'holding up' qualities of the ore itself, and slope of the ore body. Essential, or at least highly desirable conditions include the following:

- (1) The walls should be very strong and as free as possible from faulting and jointing.
- (2) The walls should not dip at less than 45° to 50°.
- (3) The ore should be tough and strong enough to allow a good safe back over any benches.
- (4) The ore body should be at least 30 feet wide, although, if the walls clean off well, mining by this method with a lesser width might be feasible.

⁶ Corlett, A. V., manager, and McLeod, G. D., mine superintendent, Aldermac Copper Corporation, Ltd., Arntfield, Quebec, Canada: A Mining Method for Large Ore Bodies.

As the required "bulk breakage" depends on having a wide, free face and heavy bench, it is quite evident that a very narrow and small ore body could not be successfully mined by long diamond-drill holes.

The two ore veins in the Anvil-Palms mine are narrow, and the footwall is unstable, although it holds up long enough to permit retreat before caving rock mixes with blasted ore.

Four diamond-drill machines of three different makes are in use at the Anvil-Palms mine. All are operated with compressed air. "EX" bits, set by a bortz, are used. From 50 to 200 linear feet of hole is drilled with each bit before replacement with a new bit becomes necessary. Worn bits are returned to the manufacturer on a "salvage-trade-in-value" basis in the purchase of new bits.

A drill crew consists of a runner and a helper. It has been found that young high-school graduates, following a short training period, become excellent drill operators, their sole duties being confined to operation of the drills. Development work is done by miners and blasting by a special blasting crew. On an average, about 80 linear feet of hole a shift is drilled by each crew.

Anvil-Palms mine officials consider the new stoping system, in connection with the diamond-drilled blast holes, to be a safe method of mining and believe that it will prove to be an economical method as well. Less development work is needed than is required in sublevel-caving and sublevel-stoping operations. Although speedier drilling can be done in some ground with the use of percussion drills, the deeper holes made possible with diamond drills offset such advantage, which is usually local.

CONCLUSIONS

In the Soudan mine:

1. Some ground that is almost impossible to drill with percussion drills is being successfully drilled with diamond drills.
2. A maximum of 12 feet of hole a shift is drilled with a percussion drill compared to 40 feet with a diamond drill.
3. About three times the hole footage can be drilled from a diamond drill set-up than from a percussion-drill set-up.
4. The thunderous and objectionable noise of percussion drills in stoping operations is eliminated through the use of diamond drills.
5. The cost of drilling blast holes with diamond drills is 35 percent less than with percussion drills when detachable bits are used.
6. Percussion drills in stopes are being replaced by diamond drills as rapidly as they can be obtained. About 60 percent of stope drilling is now done with diamond drills.

7. Diamond drilling in drifting operations is in an experimental stage, but complete replacement of percussion drills with diamond drills is anticipated.

In the Anvil-Palms mine:

1. With diamond drills for making deep blast holes, a system of open stoping has been developed that is more suitable to mining the narrow ore veins than the sublevel-stoping and sublevel-caving systems otherwise in use.
2. Difficulties of mining alongside the unstable footwall rock have been largely overcome in the use of the new stoping system.
3. Although comparative figures had not been obtained, more rapid drilling is done with a diamond drill than with a percussion drill.
4. An average of 80 linear feet of hole a shift is obtained with each second drill.
5. Fifty to 200 linear feet of hole is drilled with a bit before recement in diamond drilling.
6. Diamond drilling of blast holes is temporarily suspended pending the completion of development work on a new stoping area.

Based on diamond-drilling experience at the Soudan and Anvil-Palms mines, at other locations where this type of drilling is employed, it can be concluded that the dust made while drilling blast holes is materially reduced as compared with wet-type percussion drills. Due to the rapid revolution of the diamond-drill bit and the pressure exerted on the bit in drilling, a constant flow of water at the bottom of the hole is necessarily maintained, which minimizes the quantity of dust from this source. On the contrary, although wet-type percussion drilling is employed, this type of drill can be operated dry often is in starting holes. More or less dust is invariably made in connection with dry drilling.